LARGE EDDY SIMULATION OF TURBULENT FLOWS AND DIRECT/DECOUPLED SIMULATIONS OF AEROACOUSTICS - PRESENT STATUS AND FUTURE PROSPECT -

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Abstract: Due to rapid progress in the performance of high-end computers, numerical prediction of fluid flow and flow-induced sound is expected to become a vital tool for aero- and hydro- dynamic design of various flow-related products. This presentation focuses on the applications of large-scale numerical simulations to complex engineering problems with a particular emphasis placed on the low-speed flows. Flow field computations are based on a large eddy simulation that directly computes all active eddies in the flow and models only those eddies responsible for energy dissipations. The sound generated from low-speed turbulent flows are computed either by direct numerical simulation or by decoupled methods, according to whether or not the feedback effects of the generated sound onto the source flow field can be neglected. Several numerical examples are presented in order to elucidate the present status of such computational methods and discussion on the future prospects will also be given.

Key Words : Large Eddy Simulation, Low-speed Turbulent Flows, Aeroacoustics, Engineering Applications, Large-Scale Computations

1. DIRECT SIMULATONS

Direct simulations of sound, which simultaneously compute flow and sound fields by solving the compressible Navier-Stokes equations numerically, are accompanied with difficulties that essentially originate from the differences in the length scale and fluctuating magnitude of the source and sound fields. This is particularly true for low-speed (i.e. low Mach number) flows for which the above differences become very large. However, this is the only method that is applicable to the prediction of flow and sound fields where feedback effects of the sound onto the source flow fields are essential. Once a feedback loop between the flow and sound fields develops, intense peak sound results in many cases even for low-speed flows and when acoustical resonance occurs at the same time, which intensifies the effects of the feedback, the peak sound may become so intense that it may cause mechanical fatigue to nearby components. Therefore, in the aerodynamic design of many flow-related products, it is of great importance to prevent such a feedback loop from developing.

Due to the reason mentioned already, applications of direct simulation of sound to low-speed aeroacoustics with complicated geometries is not applicable at present and does not seem to become feasible in the future. However, it is possible to apply direct simulation to a problem that is simplified from, but still possesses the essential features of, a real-world problem. As such example, Fig. 1 shows the flow and sound field for an open cavity placed in a turbulent boundary layer (TBL) with a modest Mach and Reynolds numbers[1]. All the important scales ranging from small longitudinal vortices in the TBL to acoustic wave are resolved by the 6th order compact finite difference with 10th order terms that is introduced in order to model dissipation to heat and dampen otherwise possible numerical instabilities associated with the central difference[2]. This simulation has revealed various

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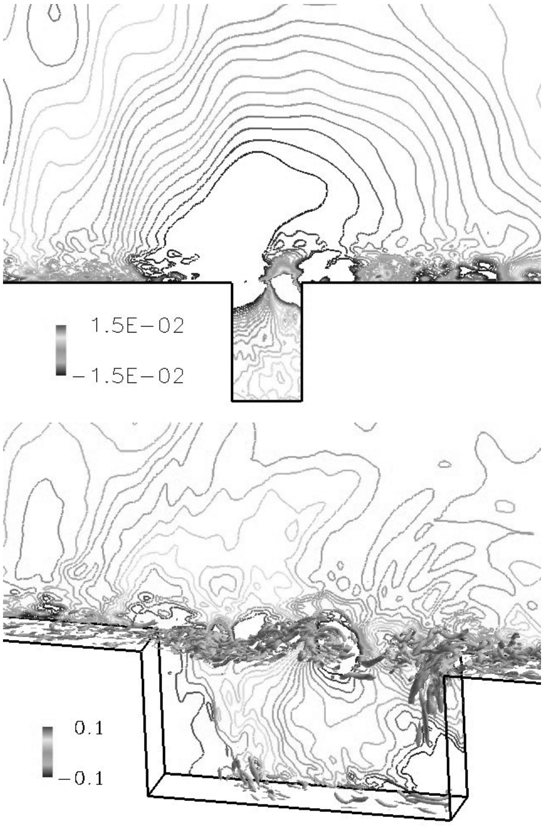

Fig. 1 Flow and sound fields computed by direct sound simulation for turbulent cavity flows with a low (upper) and high (lower) aspect ratio

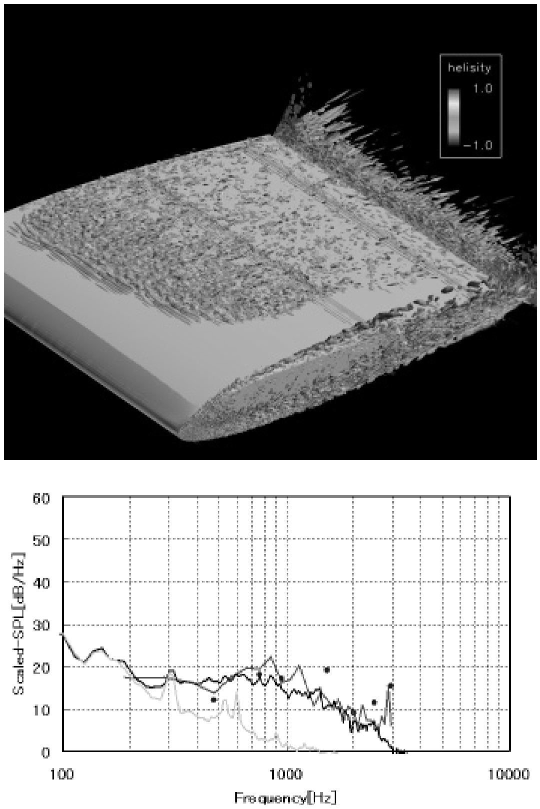

Fig. 2 Instantaneous vortical structures (upper) and comparison of the computed and measured sound pressure level (lower) for flow around a two-dimensional aerofoil accompanied by tip vortices.

important aspects of turbulent cavity flows that have been unknown. The roll-up of large scale vortices, the role of the small-scale vortices and sound waves and acoustic emission are all discussed in detail in the presentation, where applications to automobile engineering will also be shown[3].

2. Decoupled Simulations

Decoupled simulations predict sound field by solving acoustical equations with given sound sources predicted by flow-field computations. Various methods of this category have been proposed in the literature, but all those methods assume that alternation of the source flow fields by the sound wave propagation is negligibly small. This assumption eliminates the difficulties associated with the direct simulation and therefore, decoupled simulations are expected to become a powerful engineering tool for the prediction of complicated aeroacoutics for various flow-related products.

Since the governing equations for acoustical field is linear except for very intense sound for which non linearity appears, analytical solution is given for the simplest case where the extent of the source field is small as compared to the length scale of the acoustic wave of interest (compact sound). However, small eddies in turbulence generate high frequency (small wave length) sound that has in many cases dominant power in the overall sound pressure level. In such a case, it becomes an important issue to accurately predict reflection of the sound wave, which is primarily radiated from vortices in the flow, at the solid boundary [4,5]. Figure 2 presents source vortical structures and a comparison of the far-field sound pressure level for NACA0012 aerofoil with a finite spanwise length. The flow field is computed by an incompressible flow solver, FrontFlow/blue[6], based on a large-eddy simulation with approximately 40 million hexahedral finite elements and acoustics field is predicted by solving the Helmholtz equation that governs acoustical field. The comparison with the predicted and measured sound pressure level is quire promising. Various engineering applications of this method will be discussed in the presentation(e.g. [7]).

3. Future Prospects

In several years, we will certainly be armed with Peta-Flops (1015 Flops) computing power with million of processing cores. At this era, flow field computations with 1010 to 1011 grid cells will become feasible and one can resolve smallest but active eddies in turbulent boundary layers with a modest (106) Reynolds number in many engineering problems. This will partially replace wind tunnel tests and provide researchers and engineers with much deeper understanding on the flow physics of their products. But, as will be discussed in the presentation, many new issues associated with such a large-scale computation will have to be solved, which include pre-processing with the CAD date, grid generations, massively-parallel computations of the order of one million processing units, post-processing and more advanced multi-physics, multi-scale models.

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